Extravehicular Activity

- Full pressure suits and high-altitude aviation
- Early human space program
- Operational suits
- Interfaces to habitats and rovers
- Spacesuit alternatives
Spacesuit Functional Requirements

A suit has to

• Provide thermal control
• Provide a breathable atmosphere
• Hold its shape
• Move with the wearer
• Protect against external threats
• Provide communications and data interactions
Wiley Post - B. F. Goodrich, 1934
“Tomato Worm” Suits - c. 1940
XMC-2 Full Pressure Suit (ILC - 1955)
Flat Panel Joint

- **FLAT SHEET OF FABRIC AND BLADDER**
- **ROLLING CONVOLUTE**
- **SHOULDER BEARING**
- **GORE PANELS**
- **ARM BEARING**
- **LACING INSERTS (FOR SIZING)**

**When sewing complete arm remains in semi-bent position**
Rolling Convolute Arm

1. Cylinder of single wall laminate (SWL) material
2. Cylinder foreshortened by series of "tucks" or folds, telescope-like
3. Metal bands inserted in folds
4. Metal bands connected by longitudinal restraints
5. Fabric rolls over bands on front of joint, and rolls out on back of joint
Toroidal Joint Construction
Toroidal Joint Actuation
Role of Neutral Axis Restraints
Soft Goods - Hardware Interfaces

Figure 1-18 Bonded roving fabric element attachment method (courtesy of NASA).

Figure 1-19 Bolted clamp and penetration fabric attachment method (courtesy of NASA).

Clamping ring
Clamping screw

Softgood (SWL fabric)

Hardware (metal)

Bead

Clamp ring (metal) before MPF
After MPF

“O”-ring (retaining bead)
Mercury Space Suits
Gemini Pressure Suits
Figure 7.1.4. Johns Hopkins University Spherical Experiment #1 (1964).
Apollo Suit Contest

AX1C

AX6H

AX5L
Du Pont materials in Apollo moon suits were originally developed for earthbound use...

NYLON

NOMEX®

MYLAR®

DACRON®

LYCRA®

TEFLON®-COATED GLASS FIBER
Skylab A7L-B
Skylab A7L-B
Advanced Crew Escape Suits (ACES)
Shuttle Launch and Entry Suit (LES)
Boeing Starliner Launch & Entry Suit
SpaceX Launch & Entry Suit(?)
Existing Pressure Suits

EMU
Hamilton-Standard

AX-5
NASA Ames

Mark III
NASA JSC

Orlan
Russia
Shuttle EMU Sizing
Liquid Cooling Garment Designs

U.S. (ILC-Dover)

Russian
Pressure Suit Helmet Designs

- Spherical Bubble with External Visor
- Fixed Helmet with Faceplate
- Hemispherical Bubble Helmet
Pressure Suit Entry Systems

Waist Entry

Rear Entry
Hard Suits - Not a New Idea (1882)
Draeger Suit (Germany - c. 1940)
Litton RX-1
Wedge Joint Operations

1. RIGHT JOINT SEGMENT (Revolves toward top)
2. LEFT JOINT SEGMENT (Revolves toward bottom)
3. CONSTANT
NASA Ames AX-1 Hard Suit
AX-1 Ingress
AX-3 Suit Ingress
AX-3 Hybrid Suit
AES Experimental Suit
AES Shoulder and Elbow Articulation
NASA Ames AX-5 Hard Suit
Mark III Suit (JSC)
Comparative Suit Evaluations - 25 Years Ago
Single-Hand Reach Envelopes

Front Reach Comparison

Reach Envelope Square Inches

Inches Distance from Grid Board

AX-5
Mk II
STS
Two-Hand Reach Envelope

Two Hand Reach Comparison

Reach Envelope Square Inches

Inches

Distance from Grid Board

AX-5
Mk II
STS
Elbow Joint Torques

Figure 28. Mk III Elbow Dynamic Torque Curve

Figure 29. AX-5 Elbow Dynamic Torque Curve

Figure 30. Shuttle Elbow Dynamic Torque Curve
Comparative Evaluation Conclusions

- Both suits fully capable of all tasks, and comparable in performance to EMU
- AX-5 had more flexible lower torso, no restoring forces for limb motions
- Crew preferences:
  - Objected to “programming” of multi-roll joints in AX-5
  - Preferred soft components in elbows, knees, and feet
  - Did not think flexibility in lower body was desirable
- AX-5 was (apparently) heavier and required greater stowage volume
- Soft goods on Mk. III had limited operating lifetimes
Results of Comparative Assessment

- Point was moot - insufficient funding was available for next-generation suit
- EMUs adopted as standard U.S. suit on ISS
- NASA Ames suit development program terminated by the mid-1990’s
- All suit development since that time has focused on soft or hybrid suit concepts
Rear-Entry Suit Donning
Waist-Entry I-Suit (ILC)
Waist-Entry Suit Donning
Recent NASA Suit Developments

- **Shuttle EMU** 1980
- **Mark III** 1988
- **WEI-Suit** 1998
- **REI-Suit** 2005
- **Z-1** 2011
- **Z-2** 2013

*Images of Evolution of NASA Space Suits*
Z-1 Experimental Suit (JSC)
NASA Z-2 Suit Concepts
NASA wants you to choose its next spacesuit from three weird designs

By Valentina Palladino on March 25, 2014 03:30 PM · Email

DON'T MISS STORIES FOLLOW THE VERGE

Hmmm... I guess I'll pick the one with an arrow pointing at his penis.

Posted on Mar 25, 2014 | 3:30 PM

OR her...

Posted on Mar 25, 2014 | 4:08 PM

Good point; it could be pointing at her penis as well.

Posted on Mar 25, 2014 | 4:11 PM

I may have laughed too hard at this....

Posted on Mar 25, 2014 | 4:51 PM
Modified ACES EVA Suit
Voshkhod Airlock (Inflatable)
Space Shuttle Airlock (External)
Space Shuttle Airlock Interior
EMU in Shuttle Airlock
ISS Quest Airlock
ILC Inflatable Habitat and Airlock
Honeywell Inflatable Airlock (axial)
LSAT Airlock

- 5.5 m³
- Air density 0.6664 kg/m³ (8 psi with 32% O₂)
- Loses 0.128 kg of O₂, 0.272 kg of N₂ per depress
- Depress time 0.7 hrs
LSAT Suitlock
Z-1 Suit in Suitport Test
LSAT Suitports
Suitlock, Suitport Consumables

- **Suitlock**
  - 0.123 kg O$_2$
  - 0.229 kg N$_2$
  - 50 min depress time

- **Suitport**
  - 0.016 kg O$_2$
  - 0.030 kg N$_2$
  - 2 min depress time
Suitport in NASA SEV Rover
Suitlock Concept

Patent 5,697,108 (NASA Ames) - Sketch taken from Hazmat application
EVA Optimum Work Envelope

- 18 inches
- 5 inches
- 13 inches
- 26 inch diameter cylinder
- 16 inch diameter cylinder
- 55.5 inches
- 54 inches
- Origin at the 4 bolt pattern on the STS PFR (where the base plate bolts to the pitch and roll joint). PFR pitched forward 15 degrees.
Two Human-Powered Vehicles
A Vision of the Future of EVA

• The conventional space suit is a human-powered device
• As such, it can never do more than asymptotically approach nude-body performance
• The next step in space suit evolution is to use it to give the wearer superhuman capabilities
  – Sensors (telescopic, microscopic, multispectral)
  – Brains (advanced computing and data bases)
  – Muscles (robotic augmentation/amplification)
  – Appendages (integrated manipulators)
• The next step is the RoboSuit: an EVA/robot symbiosis
Augmenting Human Sensing

- **Interior sensors**
  - Kinematic sensors (body joint angles)
  - Biomedical sensors (heart rate, breathing rate)
  - Workload sensors (VO2, LCVG enthalpy change)
  - Neuromuscular sensors (EMG, AMG)

- **Exterior sensors**
  - Proximity sensors
  - Noncontact temperature sensors
  - Navigational data

- **Visual sensors**
  - Microscopic and telescopic
  - Multispectral
  - Thermal emission spectroscopy
Suit Instrumentation

- Goal is to fully instrument human/suit system for quantitative performance metrics
- Extensive sensor suite
  - Body joint angles
  - Neuromuscular activity and fatigue measurement
- Metabolic workload sensors
- Direct measurement of reach envelopes, forces and torque
Increasing Data Bandwidth to the Human

- Visual displays
  - Head mounted
  - Helmet mounted
- Aural displays
  - Local sound
  - Synthesized sound
- Haptic displays
- Tactile displays
Augmenting Human Cognition

• Rote memory
  – Equipment checklists
  – Operating procedures

• Diagnostics
  – Suit built-in self test
  – Ancillary equipment

• Planning
  – Route planning
  – Orbital mechanics

• Scientific knowledge
  – Access to data bases
  – “PI in a box”
Augmenting Human Actuation

• Mobility
  – Planetary surfaces
  – Atmospheric flight
  – Microgravity mobility

• Manipulation
  – Controlling external agents
  – Targeted suit augmentation
  – Global suit augmentation
Past Suit Mobility Augmentation
Approaches to EVA Remote Driving

• Compared joystick, trackpad, mouse, and gestural control for simple computer-simulated driving task

• Tasks performed in EMU gloves at 4.3 psi (glove box)

• Results indicated clear advantages of gestural control (precision, accuracy, bandwidth)
I-Suit EVA/Robotic Field Tests

- Implemented gestural control of rover for field trials (2004)
  - Tracking target and grasp sensors on glove TMG
  - Tracking camera on helmet visor assembly
- Demonstrate gestural control in total system application (with JSC/EC, ILC-Dover)
  - Controlling camera on pan-tilt unit
  - Driving EVA support vehicle
  - Geology camera on staff
  - Images fed to head-mounted display
- Investigate EVA-designated robotic geological sampling at UMd following field trials
Free-Flying EVA Tool Tender

- Adapted SCAMP free-flying vehicle for EVA support
- Carried EVA tool board for simulated crew activities
- Reduced crew time required for translation, tool handling
- Minimizes use of valuable “real estate” on front of suit for tool storage
- Provides external view of EVA operations
EVA/Robotic Cooperation Background

- SSL involvement in EVA/robotic interactions dates back to early 1980’s
- Extensive EVA/robotic servicing tests of Hubble beginning in 1989
- Multiagent operations (EVA, dexterous robot, free-flier, positioning arm) beginning in mid-90’s
- Demonstrated ability of telerobot to rescue incapacitated EVA crew
Robotic Augmentation for EVA Servicing

- Studied application of robotics to EVA HST servicing
- Final approach: robot-augmented manipulator foot restraints
- System reduced SM-4 EVA time requirement by 40%
- Further time savings probable through optimal scheduling
EVA/Robotic Servicing of HST
Ranger Application to HST SM1

EVA Daily Average from SM1

- EVA Day 1
- EVA Day 2
- EVA Day 3
- EVA Day 4
- EVA Day 5

Time (hrs)

- 9:00
- 12:00
- 15:00
- 18:00
- 21:00

- EV1 - with Ranger
- Ranger (during EVA)
- EV2 - with Ranger
- Ranger (pre-EVA)
- Ranger (post-EVA)
Grasp Analysis of SM-3B

Numbers refer to instances of grasp type over five EVAs
Total discrete end effector types required ~8-10
Results of EVA Dexterity Analysis

• Broke 63 crew-hrs of EVA activity on SM-3B into 1860 task primitives
• 82.5% of task primitives are viable candidates for 2DOF robotic end effectors
  – 62.2% 1DOF tasks
  – 2.8% 2DOF tasks
  – 17.5% tasks performed differently by robot than EVA (e.g., torque settings)
• 4.1% inherently dexterous tasks
• 13.1% cannot be categorized from existing video
• All SM-3B robotic tasks can be performed by suite of 8-10 different end effectors
Suit-Integrated Manipulator
Morphing Space Suit Components

- Initial focus on morphing upper torso ("MUT")
- Linear actuators in restraint wires to control position and attitude of neck ring, shoulder bearings, waist ring
- Analytical approach: four intercorrelated Stewart platforms
- Nonideal effects of pressurized fabric on wire runs
- Being extended to power-assisted arm segments
Power-Augmented EMU Glove

- ILC-Dover designed EMU glove with MCP joint
- UMd added robotic actuator for MCP joint, control system to follow hand movements
- Reduced force required for MCP actuation from 16 pounds to 12 ounces
- No penetration of pressure bladder (all actuators, sensors, and controls external)
Power Suit

- Hard suit (AX-5 shown here) ideal starting point
  - All rotary joints
  - Rigid structure for actuator integration
- Use body joint angle sensors for actuator command inputs
- Provide hard stops to protect wearer
- Start with augmentation; evolve to amplification
Possible Applications of a Power Suit

- In-flight EVA training - suit as haptic display device
- Control-mediated operations - limiting velocity, energy input, increasing human accuracy
- Human workload reduction - commanding suit to hold tool in hand, position in foot restraints
- Controllable compliance - select rigidity for microgravity foot restraint activities
- Autowalk
- Integrated short-range flight capability - “jump jets”
- Self-rescue - suit returns to airlock if wearer is incapacitated
Mechanical Counterpressure Suit
Webb Space Activity Suit (1971)
Web Space Activity Suit (1971)
Mechanical Counterpressure “Concepts”
References

- Kenneth S. Thomas and Harold J. McMann, US Spacesuits - Springer-Verlag, 2006